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Field performance of *Frankia*-inoculated and non-inoculated alders (*Alnus* spp.): Preliminary results

D. Burgess, L. Chatarpaul, and O. Hendrickson

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FIELD PERFORMANCE OF *FRANKIA*-INOCULATED AND NON-INOCULATED ALDERS (*ALNUS* SPP.): PRELIMINARY RESULTS

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ABSTRACT

This study describes field trials with native and exotic alders established to assess the potential of tree-sized exotic alders for use in forestry in central Canada. A study of Frankia inoculation effects on growth and survival is also included. Seedlings were started in the greenhouse, transplanted into nursery seedbeds, and field outplanted the following spring. Survival and growth were assessed annually and showed significant differences between species. In these studies, the exotic alders Alnus glutinosa (L.) Gaertn., A. incana ssp. incana (L.) Moench, and A. japonica (Thunb.) Steud. outgrew the local native species A. incana ssp. rugosa (Du Roi) Clausen. and A. viridis ssp. crispa (Ait.) Turrill. Other species evaluated included A. cremastogyne Burk., A. rubra Bong., A. viridis ssp. sinuata (Reg.) Löve & Löve, and A. incana ssp. tenuifolia (Nutt.) Breitung. Survival was high for all species except A. cremastogyne which was killed by frost. Average heights of 4-year-old trees ranged from a low of 0.97 m for A. viridis ssp. sinuata to 4.7 m for A. japonica. Diameter (dbh) ranged for the four largest species from 1.67 cm for A. incana ssp. rugosa up to 3.3 cm for A. incana ssp. incana and A. japonica. In the inoculation study, seedlings either were treated with Frankia strain ACN1^{AG}, or received a slow-release N fertilizer (without inoculum). These two production systems had variable effects on first-year growth in nursery seedbeds, but inoculated plants showed significantly greater height growth at the field site.

RÉSUMÉ

L'étude décrit l'essai sur le terrain d'aulnes indigènes et exotiques établis afin d'évaluer les possibilités forestières d'aulnes exotiques arborescents dans le centre du Canada. Elle englobe aussi les effets de l'inoculation des aulnes par Frankia sur l'accroissement et la survie. Après germination en serre, les semis ont été repiqués en pépinière, sur des planches, puis transplantés en place, le printemps suivant. La survie et l'accroissement ont été évalués à chaque année et ont révélé des écarts notables entre les espèces et les sous-espèces. Ainsi, les aulnes exotiques Alnus glutinosa (L.) Gaertn., A. incana ssp. incana (L.) Moench et A. japonica (Thunb.) Steud. ont crû plus vite que les sous-espèces indigènes A. incana ssp. rugosa (Du Roi) Clausen. et A. viridis ssp. crispa (Ait.) Turrill. D'autres sous-espèces étudiées comprenaient A. cremastogyne Burk., A. rubra Bong., A. viridis spp. sinuata (Reg.) Löve & Löve et A. incana ssp. tenuifolia (Nutt.) Breitung. La survie de toutes les sous-espèces sauf A. cremastogyne, tuée par le gel, était élevée. La hauteur moyenne des sujets de 4 ans variait de 0,97 m (A. viridis ssp. sinuata) à 4,7 m (A. japonica). Chez les 4 sous-espèces au diamètre (dhp) le plus large, ce dernier variait de 1,67 cm (A. incana ssp. rugosa) à 3,3 cm (A. incana ssp. incana et A. japonica). Dans la comparaison des effets de l'inoculation, les semis ont été soit traités avec la souche ACN1^{AG}, soit soumis à un amendement azoté à libération graduelle (sans inoculation). Ces deux régimes ont eu des effets variables sur l'accroissement dans les planches de pépinière, la première année, mais, chez les sujets inoculés, l'accroissement en hauteur, après la transplantation, était notablement supérieur.

FIELD PERFORMANCE OF *FRANKIA*-INOCULATED AND NON-INOCULATED ALDERS (*ALNUS* SPP.): PRELIMINARY RESULTS

INTRODUCTION

Most forest soils are deficient in nitrogen in a form that can be utilized to support maximum tree growth (Gordon and Dawson 1979). Chemical fertilizers can be applied to raise productivity, but they are energy demanding, relatively scarce, and costly to manufacture and use (Burgess 1984).

Biological nitrogen fixation is a process which can be incorporated into management strategies, both to improve soil fertility and reduce the demand for chemical fertilizers. In agriculture legume use, including inoculation with *Rhizobium*, for these purposes, is widespread, but there is some concern that the photosynthate supplied by the host plant to support the N_2-fixing and NH_4^+-assimilating activities may lead to significant reductions in yield (Schubert 1982). In forestry, the level of management is generally less intensive and, possibly, biological nitrogen fixation may be more easily adopted into management regimes (Chatarpaul and Carlisle 1983).

Actinomycete-nodulated N-fixing angiosperms such as *Alnus* spp., *Myrica* spp., *Elaeagnus* spp., and *Casuarina* spp. appear particularly promising for use in forestry (Tarrant and Trappe 1971, Torrey 1978, Zavitkovski et al. 1979). Alders (*Alnus* spp.) are the most important members of this group in north and south temperate regions (Silvester 1977). They are widely distributed throughout the north temperate zone and grow on a wide range of sites. Alders are relatively fast growing and their ability to sprout from stumps left after harvesting eliminates the need (and cost) of replanting after each harvest.

Alders can be used as a fibre source, for soil improvement, and to accelerate growth of companion trees (Tarrant and Trappe 1971). Alders interplanted with black walnut *Juglans nigra* (Clark and Williams 1979), Douglas-fir *Pseudotsuga menziesii* [Mirb.] Franco (Miller and Murray 1978), and hybrid poplar *Populus* spp. (DeBell and Radwan 1979, Hansen and Dawson 1982, Cote and Camire 1984) have resulted in significantly higher yields, although the positive effect of interplanting does not always occur (Plass 1977, Heilman and Stettler 1983). Such results will be of even greater importance as forest management intensifies.

Further intensification of forest management is likely as timber supplies decline and the demand for wood rises. Meanwhile, the forest land base is shrinking in response to conservation, recreation, and scientific needs (Carlisle and Chatarpaul 1984). Forest managers are faced with the task of supplying more wood from a smaller area, placing greater pressures on forest soils. The intensification of forest management will involve greater use of shorter rotations, biomass harvesting, and more intensive culture, including the use of N-fixing species such as alders.

A better understanding of alders is required before their management can be optimized (Hall et al. 1979). European black alder *Alnus glutinosa*

(L.) Gaertn. has been studied most extensively and is now widely used for land reclamation (Gordon and Hall 1978). Other alder species such as grey alder Alnus incana ssp. incana (L.) Moench, Italian alder Alnus cordata Desf., and red alder Alnus rubra Bong. have also received some attention (Miller 1982).

Alnus is a diverse and widespread genus. Some species such as the only two alder species native to eastern Canada (Alnus viridis ssp. crispa (Ait.) Turrill, Alnus incana ssp. rugosa (Du Roi) Clausen) (Daly 1966) are shrub-like in form. In North America, trials of the tree-sized Alnus glutinosa have been conducted with seedlots collected from a limited part of its range, but other exotic alders have not been studied.

This paper describes growth trials with native and exotic alders aimed particularly at assessing the potential of tree-sized exotic alders for use in forestry in central Canada. Preliminary data on a field experiment to examine the effects of Frankia inoculation on alder growth and survival are also described.

MATERIALS AND METHODS

Site description

The field site was located within the research forest of the Petawawa National Forestry Institute (PNFI), Chalk River, Ontario, Canada (46°00'N, 77°26'W), at an elevation of 180 m. The climate is continental with mean January and July temperatures of -13°C and 20°C respectively and a mean annual precipitation of 78 mm. The soil was a well-drained sandy loam formed on moderately acid (pH 5.8, distilled water) glacial till, with many large stones present. Drainage was good, but fertility was low (organic matter 4.8%, total N 0.15%). The site was kept in grass prior to site preparation, and had not received fertilizer or herbicide in the past 10 years. The study area was ploughed and disked the year prior to planting. It was rock-picked and rototilled before outplanting, then weeded and irrigated for one year following outplanting.

Planting stock

Alder seeds were obtained from the National Tree Seed Centre at PNFI. Four to eight seeds per cavity for each species (Table 1), depending upon previous germination trials, were sown in Hilson-type Spencer-Lemaire containers. The planting medium consisted of a 3:1 peat:vermiculite mixture, supplemented with dolomitic lime, gypsum, triple superphosphate, and micronutrients (B, Cu, Fe, Mn, Mo, Zn). Each seedling in the non-inoculated treatments received 225 mg N in the form of a slow-release fertilizer (Osmocote). A small amount of starter N(10 mg/seedling) was applied in solution to seedlings scheduled for inoculation. Inoculations were carried out on 3-4 week old seedlings. Each seedling received 3 mL of a diluted inoculum (100 mL of concentrated inoculum in 3 L of water). Frankia strain ACN1^{AG} (catalogue number ULQ0102001007, supplied by M. Lalonde, Laval University, Quebec) was the only strain used in the experiment. Seedlings were grown in the greenhouse under 24-h lighting. They were watered for 5 min. every 4 h from 8:00 a.m. to 8:00 p.m., and 5 min. at 2:00 a.m. Following germination, seedlings were thinned to one seedling per container. Starting six weeks after sowing, N-free nutrient solution, containing the following, was added weekly (per litre): KCl (0.375 g),

Table 1. Seed sources for *Alnus* species used in planting trials

Species	Origin	Latitude	Longitude	Elevation
A. cremastogyne Burk.	China	-	-	-
A. viridis ssp. *crispa* (Ait.) Turrill.	Chapleau, Ontario	47°38'N	83°15'W	460 m
A. glutinosa (L.) Gaertn.	Penzenskoi Oblast, U.S.S.R.	approx. 53°N	approx. 43°E	
A. incana ssp. *incana* (L.) Moench	Lake Dore, Ontario*	45°37'N	77°07'W	175 m
A. japonica (Thunb.) Steud.	Japan, via Scotland	-	-	-
A. rubra Bong.	Forbidden Plateau, British Columbia	49°35'N	125°16'W	1200 m
A. incana ssp. *rugosa* (Du Roi) Clausen.	Chalk River, Ontario	45°58'N	77°25'W	160 m
A. viridis ssp. *sinuata* (Reg.) Löve & Löve	McKendrick Pass, British Columbia	54°40'N	126°45'W	1190 m
A. incana ssp. *tenuifolia* Nutt.	Cranbrook, British Columbia	49°30,N	117°48'W	712 m

* Original seed source was from northern Sweden.

$CaSO_4 \cdot 2H_2O$ (0.25 g), $MgSO_4 \cdot 7H_2O$ (0.25 g), $Fe_3(PO_4)_2 \cdot 8H_2O$ (0.125 g), and $Ca_3(PO_4)_2$ (0.125 g) at a rate of 3 mL for each inoculated seedling.

The seedlings remained in the greenhouse until late May, at which time they were placed outdoors under shade racks and irrigated for a two-week 'hardening-off' period. In early June, the seedlings were transplanted into nursery seedbeds where they remained prior to sampling or until outplanting the following spring.

Experimental design and analysis

Eight alder species were included in the first field experiment: four exotic species (A. cremastogyne Bush., A. glutinosa (L.) Gaertn., A. incana ssp. incana (L.) Moench, and A. japonica (Thunb.)); two species native to eastern north America (A. viridis ssp. crispa (Ait.) Turrill., and A. incana ssp. rugosa (Du Roi) Clausen); and two species found in western North America (A. rubra Bong., and A. viridis ssp. sinuata (Reg)). These uninoculated alders were outplanted from the nursery in May 1982 in plots of 25 seedlings per plot. Plot location was completely randomized. Seedlings were spaced 1.0 x 1.0 m and were surrounded by guard rows on all sides.

A second field experiment, including both inoculated and uninoculated stock, was established at the same study site in the spring of 1983. A. japonica was not included in this study because sufficient seed was not available. In May 1983, alders were lifted from the seedbeds, and the ovendry mass (80°C) of shoots, roots, and nodules was measured on random subsamples of seven alder species: A. viridis ssp. crispa, A. glutinosa, A. incana ssp. incana, A. rubra, A. incana ssp. rugosa, A. viridis ssp. sinuata, and A. incana ssp. tenuifolia. Three species (A. viridis ssp. crispa, A. glutinosa, and A. incana ssp. incana) were transplanted to the field site. Again, plots contained 25 plants in a 1.0 x 1.0 m spacing. For each species, six plots of inoculated plants and six plots of uninoculated plants were established in a modified randomized block design. Blocks were divided evenly, with the two inoculation treatments separated by buffer zones consisting of three rows of uninoculated trees.

Survival and height growth were assessed after each year following outplanting. Where possible, diameter at breast height (dbh) measurements were taken after the second year. An ANOVA was used to analyze the data, with species and inoculation treatments (where appropriate) as main effects. Comparisons among species and treatments were made using Duncan's Multiple Range Test. Comparisons of inoculated and uninoculated plants within species were made using t-tests.

RESULTS

Of the eight alder species originally tested in the first field experiment, seven species survived the first four growing seasons. Alnus cremastogyne was killed by frost during the first winter after outplanting. The survival of the remaining Alnus species after four growing seasons was as follows: incana ssp. incana, glutinosa, incana ssp. rugosa, 100%; japonica, 98.7%; viridis ssp. crispa, 92%; viridis ssp. sinuata, 89.3%; rubra, 80%. There

was little change in survival after the first year following outplanting, except for A. rubra which continued to decline in numbers because of frost damage (from 100% to 80%). Although aboveground parts of this species were killed each winter, many root systems survived and sent up new shoots the following growing season.

There were significant differences between species in terms of both heights and diameters (Table 2). Average height measurements ranged from a low of 0.97 m for A. viridis ssp. sinuata to 4.7 m for A. japonica. Diameters were measured for the four best species. They ranged from 1.67 cm for A. incana ssp. rugosa up to 3.3 cm dbh for A. incana ssp. incana and A. japonica (Fig. 1). Alnus glutinosa had a significantly greater height increment in 1984 than either of the latter two species, and its diameter increment exceeded that of A. japonica. Consequently, under the favourable growth conditions provided, i.e. weeding and irrigation, the three exotic alders A. glutinosa, A. incana ssp. incana, and A. japonica grew well and out-performed the native alder species.

In the second experiment, biomass of shoots, roots, and nodules were recorded for both inoculated and uninoculated seedlings after one season's growth in the nursery beds (Table 3). Inoculated seedlings became well nodulated in the greenhouse, while uninoculated seedlings remained nodule-free until after transplanting into the nursery beds. All seedlings were well nodulated after one season in the nursery (Table 3). Significant species x inoculation interactions were found for all variables examined. The production system which included inoculation had a significant positive effect on the total biomass of A. rubra, A. incana ssp. rugosa, and A. viridis ssp. sinuata. There was a significant negative effect on A. glutinosa and no effect on the other species. Inoculation resulted in lower shoot-to-root ratios for A. glutinosa, A. incana ssp. incana, and A. incana ssp. tenuifolia. Other alder species showed no effect of the production system which included inoculation, but these specific results may not be meaningful because of the low numbers of seedlings sampled (Table 3).

Three species, A. viridis ssp. crispa, A. glutinosa, and A. incana ssp. incana, were transplanted from the nursery to field plots. Height measurements were taken at the time of planting and at the end of the first and second growing seasons (Table 4). Results support findings of the first experiment, with A. incana ssp. incana outgrowing the other two species. When transplanted from the nursery, inoculated plants were smaller than uninoculated ones, probably due to the latter receiving more N fertilizer at seeding. However, annual growth increments were significantly higher for inoculated plants of all three species during the following two growing seasons in the field. As a result, significant height gains over the uninoculated stock were recorded for the 3-year-old inoculated plants (+28%, +7%, and +5% for A. viridis ssp. crispa, A. glutinosa, and A. incana ssp. incana, respectively). The inoculated plants also showed less variability in the third year growth increments and overall heights after three years. Survival was 96% or better for all species x inoculation combinations.

Table 2. *Alnus* height and diameter-at-breast height (dbh) growth at the field study site

Species	Height (m)			Diameter (cm)	
	3rd-yr increment	4th-yr increment	4th-yr total	4th-yr increment	4th-yr total
A. viridis ssp. *crispa*	0.66 (0.20)e	0.44 (0.25)d	1.80 (0.33)d		
A. glutinosa	1.53 (0.27)c	1.97 (0.39)a	4.48 (0.59)b	1.59 (0.41)a	3.03 (0.66)b
A. incana ssp. *incana*	1.68 (0.31)b	1.58 (0.52)b	4.63 (0.69)ab	1.46 (0.54)ab	3.34 (0.83)a
A. japonica	1.79 (0.54)a	1.47 (0.27)b	4.73 (0.81)a	1.35 (0.46)b	3.32 (0.92)a
A. rubra	0.16 (0.25)f	0.03 (0.30)f	1.09 (0.30)e		
A. incana ssp. *rugosa*	1.02 (0.31)d	1.26 (0.23)c	3.33 (0.52)c	0.82 (0.22)c	1.67 (0.43)c
A. viridis ssp. *sinuata*	0.21 (0.15)f	0.37 (0.17)d	0.97 (0.27)e		

NOTE: Values are means, with standard deviations in parentheses. Means in columns followed by the same letter do not differ significantly at the 5% level.

Fig. 1. Field plot of 5-year-old Alnus japonica trees (photo taken in August 1985 - trees were pruned to show stem form).

Table 3. Effect of inoculation on *Alnus* growth in the nursery

Species	Plant weight (g)								Shoot/root (g/g)	
	Shoot		Root		Nodule		Total			
	Inoculation treatment (+ = $ACN1^{AG}$, − = None)									
	+	−	+	−	+	−	+	−	+	−
A. viridis ssp. *crispa*	7.6a	4.2a	5.2a	3.3a	0.20a	0.19a	13.0a	7.7a	1.4a	1.2a
A. glutinosa	1.6b	3.8a	3.0a	3.9a	0.07a	0.14a	4.7b	7.8a	0.5b	0.9a
A. incana ssp. *incana*	2.4a	3.3a	4.8a	4.0a	0.15a	0.21a	7.4a	7.5a	0.5b	0.9a
A. rubra	12.7a	4.2b	9.1a	3.8a	0.55a	0.19b	22.4a	8.3b	1.4a	1.3a
A. incana ssp. *rugosa*	9.0a	3.2b	7.3a	2.7b	0.37a	0.10b	16.7a	6.0b	1.2a	1.2a
A. viridis ssp. *sinuata*	5.3a	2.1b	4.6a	1.4b	0.64a	0.12b	10.5a	3.6b	1.1a	1.4a
A. incana ssp. *tenuifolia*	8.5a	4.7a	6.0a	2.2a	0.56a	0.11b	15.1a	7.0a	1.4b	2.1a
Average	6.5a	3.8b	5.7a	3.4b	0.36a	0.17b	12.5a	7.3b	1.0b	1.2a

Number of replicates by inoculation treatment ($ACN1^{AG}$, None): *crispa* (6, 5), *glutinosa* (6, 6), *incana* (6, 6), *rubra* (6, 3), *rugosa* (6, 3), *sinuata* (6, 3), *tenuifolia* (6, 4). Pairs of values followed by the same letter do not differ significantly at the 5% level.

Table 4. Effect of inoculation with Frankia strain ACN1[AG] on growth of three Alnus species in the field.

Time period	Species					
	A. viridis ssp. crispa		A. glutinosa		A. incana ssp. incana	
	ACN1	None	ACN1	None	ACN1	None
	---------- Annual height increment (m) ----------					
1st year*	0.42b	0.46a	0.21b	0.36a	0.39b	0.57a
2nd year	0.56a	0.43b	0.79a	0.66b	1.18a	0.96b
3rd year	0.94a	0.60b	1.58a	1.38b	1.67a	1.56b
3-year total	1.91a	1.49b	2.58a	2.41b	3.24a	3.10b
	------- Standard deviation of height increment (m) ----					
1st year*	0.15a**	0.16a	0.07b	0.10a	0.16b	0.19a
2nd year	0.23a	0.20b	0.20a	0.20a	0.29a	0.30a
3rd year	0.20b	0.29a	0.35b	0.44a	0.35b	0.48a
3-year total	0.30b	0.37a	0.47b	0.55a	0.53b	0.75a

Values for individual species for a given time period followed by the same letter do not differ significantly at the 5% level.

* 1st year = Height increment in the greenhouse and nursery (measurements made in May 1982).

** Results of F-test for equality of variances.

DISCUSSION

Growth of native and exotic alder species

The exotic alder species have outgrown the native species A. viridis ssp. crispa and A. incana ssp. rugosa in this study. Further studies will be needed to evaluate the potential of these exotic species under Canadian conditions. Nevertheless, the results presented here are encouraging.

It is suggested that other Alnus species or hybrids be examined for possible introduction into tree breeding and silvicultural programs. Exotic alder species which reach merchantable size, as well as those which supply fixed nitrogen, may prove of particular value.

Alnus japonica is one of 16 species or varieties of Alnus native to Japan (Uemura 1971). It reaches a height of up to 25 m at maturity in Japan (Rehder 1940) and, like the genus Alnus, probably originated in this area (Furlow 1979). The species consists of two varieties i.e. A. japonica var. japonica, and A. japonica var. arguta (Murai 1963). The latter variety has the more northerly distribution. A. japonica suffered slight damage from frost during the winter 1983/84 and from top dieback again over the 1984/85 winter. The larger A. japonica, furthermore, appear to be susceptible to sapsucker Sphyrapicus varius (L.) damage.

Alnus incana ssp. incana is particularly valued in European forestry as a nurse crop because of its ability to colonize a wide range of sites (Baule and Fricker 1970). Its range extends throughout most of Europe, where it reaches up to 20 metres in height. A. incana ssp. incana has a low demand for nutrients and may prove useful for planting on Canadian forest soils of low fertility. It is capable of tolerating much drier sites than A. glutinosa but it grows best on moist sites.

Alnus glutinosa is native to most of Europe, eastern Russia, and North Africa where it reaches a height of up to 24 meters (McVean 1953). It grows best along streams and rivers or on other sites where water is not limiting. Although it initially grew more slowly in the experiment reported here, A. glutinosa appears now to be overtaking A. incana ssp. incana and A. japonica. This change may reflect the increased competition between larger seedlings at the confining 1.0 x 1.0 m spacing.

A lack of both competition and moisture stress contributed to the relatively high rates of growth reported here. These growth limiting factors will have to be taken into consideration before an individual species performance can be fully recognized. Nevertheless, based on the good growth of the exotic alder tree species, it is felt that further investigations of their potential are warranted.

Effects of Frankia inoculation

Results reported here indicate that changing the production system to produce well-nodulated seedlings in the greenhouse can have significant effects on subsequent plant growth. Earlier studies (Berry and Torrey 1985, Périnet et al. 1985, Stowers and Smith 1985) demonstrated that many factors, such as the quantity and quality of inoculum and the type, nutritional status, and pH of

the growing media are important in obtaining good nodulation and growth of container-grown Alnus in the greenhouse. The production system used in this study resulted in both positive and negative effects, depending on the alder species examined. Furthermore, the effects changed with time. Reduced height growth in the nursery was reversed following subsequent outplanting in field plots.

In this study, inoculation with Frankia strain ACN1^{AG} had the greatest effect on growth of Alnus viridis ssp. crispa, the original host plant for this Frankia strain. Naturally-occurring Frankia-Alnus associations do not always give optimal results. Teissier-du-Cros et al. (1984) obtained varying results after inoculating nursery seed beds with a Frankia strain originally isolated from nodules of A. rubra. In one experiment, they found that inoculation treatment reduced height growth in two of three provenances of A. rubra, the original host plant of the Frankia strain used in the experiment. All seedlings in their study, as in the study reported here, formed nodules in nursery seedbeds whether or not inoculum was applied. Hall, McNabb, Maynard, and Green (1979) found that a crushed nodule preparation from A. rubra gave poorer nodulation results on its host plant than a preparation obtained from A. glutinosa. Considerable natural variation occurs in associations of Frankia with A. viridis ssp. crispa (Normand and Lalonde 1982) and A. glutinosa (Hall et al., 1979). These latter two studies indicate that abundantly-sporulating Frankia strains yield suboptimal results when applied on their host plants. Other work (e.g. Carpenter et al. 1984, Dawson and Sun 1981) has demonstrated significant effects of different Frankia isolates on growth of non-host plants.

Results also suggest that short-term field studies may be misleading, and that trials should be conducted over periods of several years. In this experiment a negative effect of inoculation and low inorganic N application on height growth was noted after one year in the nursery for all three species, but this was replaced by a positive growth response in the field over the next two years. However, this may be just a result of the lower and perhaps more favourable shoot-to-root ratio characteristic of inoculated seedlings. Reduced variability in inoculated plants suggests that inoculation treatments can produce more uniform growth characteristics and, conversely, that naturally-occurring Frankia strains vary in effectivity.

Little is known about the effectiveness of Frankia strains found in Canadian soils, particularly while in association with introduced host species. Normand and Lalonde (1982) have succeeded in isolating over 200 Frankia strains from A. viridis ssp. crispa and A. incana ssp. rugosa provenances growing in Quebec. Nevertheless, no comparisons have been made between native Frankia strains with those found, for example, in the region of Asia where Alnus and, possibly, Frankia are believed to originate. Considerable research effort is needed before optimum host-endophyte combinations can be identified and utilized.

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